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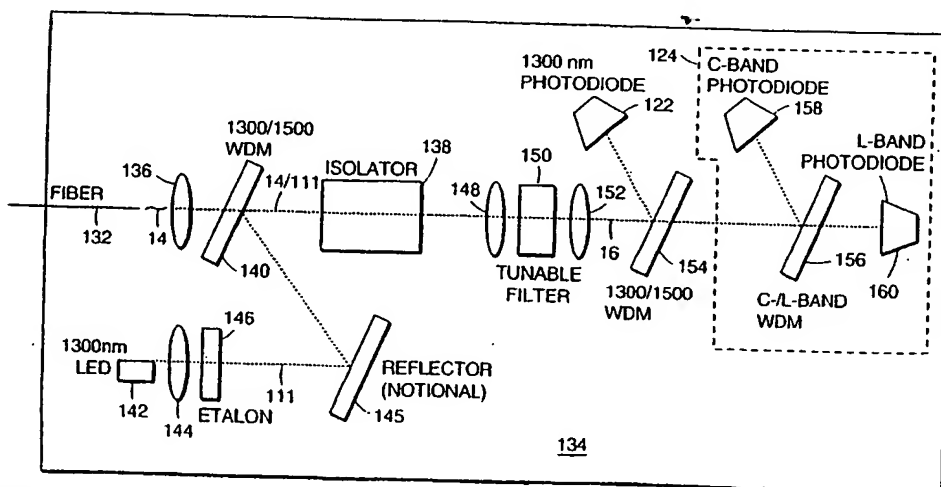
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(54) Title: OPTICAL CHANNEL MONITORING SYSTEM WITH SELF-CALIBRATION



(57) Abstract: An optical monitoring system provides for out-of-band calibration. As a result, calibration can be performed simul-
taneously with monitoring. This can be used to accomplish faster and/or more accurate scanning. In addition, the need for complex
switching and/or multiplexing capabilities can be avoided. The system comprises a signal source of an optical signal having spectrally
separated channels, which are distributed within a spectral band, such as a WDM signal. A reference source generates a reference
signal outside of the spectral band. A tunable filter filters the optical signal and the reference signal. A reference signal detector then
detects the filtered reference signal, while an optical signal detector detects the filtered optical signal.

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Optical Channel Monitoring System with Self-Calibration

BACKGROUND OF THE INVENTION

Wavelength division multiplexing (WDM) systems typically comprise
20 multiple separately modulated laser diodes at the transmitter. These laser diodes are
tuned to operate at different wavelengths. When combined in an optical fiber, the
WDM optical signal comprises a corresponding number of spectrally separated
channels. Along the transmission link, the channels are typically collectively
amplified in gain fiber, such as erbium-doped fiber and/or regular fiber, in a Raman
25 pumping scheme. At the receiving end, the channels are usually separated from each
other using thin film filter systems, to thereby enable detection by separate
photodiodes.

The advantage of WDM systems is that the transmission capacity of a single
fiber can be increased. Historically, only a single channel was transmitted in each
30 optical fiber. In contrast, modern WDM systems contemplate hundreds or thousands
of spectrally separated channels per fiber. This yields concomitant increases in the
data rate capabilities of each fiber and can enable channel add/drop systems.
Moreover, the cost per bit of data for WDM systems is typically less than

comparable non-multiplexed systems. This is because any amplification system required along the link can essentially be shared by all of the separate channels transmitted in a single fiber link. With non-multiplexed systems, each channel/fiber would require its own amplification system.

5 Nonetheless, there are challenges associated with implementing WDM systems. First, the transmitters and receivers are substantially more complex since, in addition to the laser diodes and receivers, additional optical components are required to combine the channels into, and separate out the channels from, the WDM optical signal. Moreover, there is the danger of channel drift where the channels
10 loose their spectral separation and overlap each other. This interferes with channel separation and demodulation at the receiving end.

SUMMARY OF THE INVENTION

In order to ensure that proper guard bands are maintained between adjacent channels and to also ensure that the carrier frequencies or wavelengths of the
15 channels are correct both relative to other channels and relative to their wavelength assignments, optical monitoring systems are required in most WDM transmission systems. They are also useful in WDM channel routing systems, such as add/drop multiplexers and switches to ensure that the specific optical channels are being property controlled. Further, information concerning the relative and absolute
20 powers in the optical channels is important as feedback to variable attenuators, for example.

Existing systems, however, suffer from a number of performance/complexity problems. In order to enable accurate, absolute wavelength discrimination, some reference signal source must typically be added to the signal path, filtered by the
25 tunable filter element, and detected. This typically requires time-multiplexing and/or switching components. Moreover, there can be accuracy concerns surrounding the fact that the monitoring system is either in a calibration mode or a monitoring mode

and the switching between the two can affect the operation of the tunable element in way that cannot be characterized.

The present invention is directed to an optical-monitoring system. It provides for out-of-band calibration. As a result, calibration can be performed simultaneously
5 with monitoring. This can be used to accomplish faster and/or more accurate scanning. In addition, the need for complex switching and/or multiplexing capabilities can be avoided.

In general, according to one aspect, the invention features an optical monitoring system. It comprises a signal source of an optical signal having
10 spectrally separated channels, which are distributed within a spectral band, such as a WDM signal. A reference source generates a reference signal outside of the spectral band. A tunable filter filters the optical signal and the reference signal. A reference signal detector then detects the filtered reference signal, while an optical signal detector detects the filtered optical signal. As such, the system provides for out-of-
15 band calibration and the concomitant advantages.

In specific embodiments, an isolator is provided to suppress back reflections into the signal source, such as a fiber pigtail endface. The reference source preferably comprises a broadband source and an etalon, which generates a reference signal with stable spectral characteristics from the broadband. Presently, the
20 broadband source is a super luminescent LED.

In the preferred embodiment, the filter simultaneously filters the optical signal and the reference signal by selection of the filter's free spectral range and where the filter modes are spectrally located. This, in combination with the simultaneous detection, allows a processor to calibrate the monitoring system while
25 monitoring the optical signal, thereby enabling more accurate, absolute spectral analysis of the optical signal.

In general, according to another aspect, the invention can also be characterized in the context of a method for optical signal monitoring. This method

comprises receiving an optical signal having spectrally separated channels, distributed within a spectral band. A reference signal is also generated. The optical signal and the reference signal are then actively filtered, and the filtered reference signal and the filtered optical signal are then detected simultaneously. The spectral characteristics of the optical signal are analyzed by reference to the filtered reference signal.

The above and other features of the invention including various novel details of construction and combinations of parts, and other advantages, will now be more particularly described with reference to the accompanying drawings and pointed out in the claims. It will be understood that the particular method and device embodying the invention are shown by way of illustration and not as a limitation of the invention. The principles and features of this invention may be employed in various and numerous embodiments without departing from the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale; emphasis has instead been placed upon illustrating the principles of the invention. Of the drawings:

Fig. 1 is a schematic, block diagram illustrating an embodiment of the optical monitoring system with insets showing the spectral characteristics of the WDM signal and filter transfer function; according to the present invention;

Figs. 2A, 2B, and 2C are spectral plots of exemplary WDM signals illustrating various problems that can be diagnosed with the optical channel monitoring system of the present invention;

Fig. 3 is a more detailed block diagram illustrating the optical train of a first embodiment of the optical channel monitoring system of the present invention;

Fig. 4 is a spectral plot illustrating the WDM system and reference signals of the first embodiment of the optical channel monitoring system of the present invention;

Fig. 5 is a perspective view of the integrated optical channel monitoring system of the first embodiment of the present invention;

Fig. 6 is a partial perspective view showing a hermetic package with its top removed and the optical bench installed inside the package;

Fig. 7 is a schematic diagram showing an alternative implementation of a portion of the optical train surrounding the tunable filter in which the filter is arranged in a double pass configuration;

Fig. 8 is a spectral plot of the filter's transfer function in a single and double pass configuration, according to the invention; and

Fig. 9 is an optical train of an optical power monitor without the integrated reference signal source/detector.

15 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 illustrates an optical system monitoring system 100, which has been constructed according to the principles of the present invention.

In the preferred or typical implementation, the system receives a WDM signal 14, the spectral characteristics of which are illustrated by inset plot 10. Specifically, plot 10 shows power as a function of wavelength. The WDM signal 14 comprises multiple channels or modulated carrier signals 12. In the present scheme, these channels are distributed in two bands, typically termed the C-band, which stretches from 1530 to 1565 nanometers (nm), and the L-band, which stretches from 1570-1605 nm.

The WDM signal 14 enters the monitoring system 100. According to the first embodiment, a wavelength reference signal 111 from a reference source 110 is added to the WDM signal 14. The combined WDM and wavelength reference signal 14/111 is then filtered by a tunable filter 150. Inset plot 114 illustrates an exemplary filter transfer function for the tunable filter 150. The transmission peak 116 is
5 variable based upon a control signal 120, which is generated by the driver electronics 118 under control of the controller 128. The driver electronics include includes a DC-DC power supply, a ramp generator, a thermo-electric cooler drive circuit, and LED driver.

10 The combined optical signal 16, which has been filtered by the tunable filter, includes both the filtered wavelength reference signal and the filtered WDM signal 14. The filtered reference signal is then detected by a reference detector 122, and the filtered WDM signal is detected by a signal detector system 124. These detectors yield electronic signals that are received by post processing electronics 126. A
15 subsequent controller 128 performs analysis functions such as channel inventory.

In the preferred embodiment, the post processing electronics 126 includes optical receiver circuits, the signal and wavelength reference and digital hardware, including an analog to digital converter.

Preferably, each detector operates in a differential detection scheme to
20 minimize common-mode noise with gain-switching multiplexor, to increase dynamic range. Gain switching is performed with a 4:1 multiplexor and several resistors. This configuration allows for different receiver sensitivities to be obtained via software command of the processor 128. The advantage of doing this is to allow for an increased dynamic range. Each scan is performed several times at different gains
25 and a recorded signal is combined in software.

In the preferred embodiment, the analog to digital converter samples at 200 kilo-samples per second to one Megasamples per second or higher. The controller 128 with the required RAM allows for the storage for samples and processing.

According to the preferred embodiment, the optical channel monitoring system of Fig. 1 has a number of different modes of operation. In a basic mode, i.e., a single channel scan, an increasing ramp voltage is applied to the tunable filter 150. This drives the changes in the size of the Fabry-Perot cavity of the filter 150 in a quasi-linear fashion. Because of the self calibration, the particular characteristics of the voltage ramp are not critical, since continuous calibration is performed by the inclusion of the out of band reference signal.

Figs. 2A, 2B, and 2C illustrate different problems that can be characterized by the optical system monitoring system 100. For example, in Fig. 2A, the relative strengths of the signals 12, along with their absolute signal strengths relative to the noise floor 13, are detectable. This information can be used as a control signal for an upstream or downstream gain equalizer. As illustrated in Fig. 2B, inter-channel artifacts 16 are also detected, as well as channels operating at high power levels, which is relevant to the operation of variable attenuators. Finally, as illustrated in Fig. 2C, gain tilt problems, typically added by amplification systems, are also identifiable. Nonetheless, it should be understood that the present invention has applicability to many other applications where the spectral content of an optical signal is relevant.

Fig. 3 shows the optical train of the optical channel monitoring system.

The fiber 132 terminates above an optical bench 134. The optical signal 14 is emitted out of the typically cleaved or cleaved-polished end-face of the fiber.

The optical signal is typically diverging as it is emitted from the fiber's core. It is collimated by a first collimation lens 136. Preferably, all lenses are formed utilizing mass-transport processes as described in U.S. Pat. No. 5,618,474, the teachings of which are incorporated herein by this reference in their entirety. The invention, however, is compatible with other types of microlenses such as those generated by diffractive, binary optics, gradient index processes, or refractive element replication, for example.

A dichroic mirror 140 is used to add the reference signal 111 to the optical signal 14. These dichroic mirrors or filters are typically referred to as WDM filters. In the illustrated implementation, the WDM filter 140 is reflective in a band surrounding 1300 nm, but transmissive in a band surrounding 1500 nm.

5 In the illustrated embodiment, the 1300 nm reference signal is generated by a light emitting diode 142. In one implementation, the light emitting diode is a super luminescent light emitting diode (SLED).

The diverging beam from the LED is collimated by a second collimating lens 144. An etalon 146 is used to convert the relatively wide-band signal from the
10 SLED into a reference signal with stable spectral characteristics. More specifically, the etalon 146 functions as a Fabry-Perot filter with a 200 GigaHertz (GHz) free spectral range (FSR). This effectively converts the SLED's continuous, broadband spectrum into a signal with energy peaks every 200 GHz. These peaks are stable, particularly when the temperature of the system is controlled by a thermoelectric
15 cooler or is otherwise stabilized.

A fold mirror 145 redirects the reference signal to the WDM filter 140. It should be noted, however, that this mirrors is not required, but is simply used to facilitate integration of the system on a compact bench.

The combined optical signal 14/111 is transmitted through an isolator 138.
20 This component is used to prevent back-reflections from the subsequent optical components into the fiber 132.

A first focusing lens 148 is used to focus the collimated combined beam 14/111 onto tunable filter 150. After the tunable filter, the beam is recollimated by a third collimating lens 152, and transmitted to a second dichroic/WDM filter 154.

25 The second WDM filter 154 functions to separate the filtered reference signal from the filtered optical signal in the filtered beam 16 from the tunable filter 150. In the illustrated implementation, the second WDM filter 154 is reflective in a band

around 1300 nm, but transmissive in a band around 1500 nm. As a result, the filtered reference signal is directed to the wavelength reference detector 122 for optical-electrical conversion.

The filtered optical signal is transmitted to the signal detector system 124. In the illustrated embodiment, the L- and C-bands are separated from each other by a third WDM filter 156. This WDM filter 156 is reflective to the C-band and transmissive to the L-band. As a result, the C-band of the WDM signal is detected by a C-band photodiode 158; the L-band is transmitted through the WDM filter 156 to be detected independently by an L-band photodiode 160. In other embodiments, more than two bands, such as three or four, are detected simultaneously by adding additional WDM filters and detectors.

The Fig. 3 embodiment provides for out-of-band calibration. This yields the advantage that the calibration can occur simultaneously with wavelength monitoring. Specifically, one or more of the filter's modes are used for signal detection while another mode is used to simultaneously filter the calibration signal.

In alternative embodiments, a similar stable source is used for in-band calibration. One downside to such embodiments, however, is the fact that complex post processing and/or time multiplexing functionality is required upstream of the detectors to switch between signal monitoring and signal calibration.

In alternative implementations, other LED sources are used, such as LED sources operating at approximately 1400 nm, such as an InGaAsP SLED.

The salient features of the tunable filter 150 are its selectable free spectral range. In the preferred embodiment, the free spectral range is $20 \text{ nm} < \text{FSR} < 170 \text{ nm}$ at 1550 nm wavelength. It preferably also has high finesse, *i.e.*, greater than 3,000, and a compact size.

In the preferred embodiment, the filter is as described in Patent Application Serial No. 09/649,168, by Flanders, entitled Tunable Fabry-Perot Filter, filed on an even date herewith, this application is incorporated herein by this reference.

In the preferred embodiment, a 40 nm FSR is selected. This enables
5 simultaneous scans of the C and L-bands, in addition to calibration relative to the reference band. Generally, to enable simultaneous scanning, the FSR of the filter must be greater than the bandwidth of at least one of the bands of interest so that successive modes of the filter can access both bands simultaneously. The FSR,
10 however, must be less than the combined bandwidth of bands, again to enable simultaneous access. Generally, the FSR is determined by the length l of the Fabry-Perot cavity in the filter, $FSR=2l/c$.

This three-way simultaneous scanning reduces the total scan time while providing for simultaneous calibration. In other embodiments, the free spectral range of the tunable filter is increased to 57.5 nm to enable monitoring of the optical
15 service channels that flank the C-and L-bands.

In some implementations, a spatial mode aperture is used in conjunction with the tunable filter. Such intra-filter apertures are desirable when extra cavity mode control devices are not used. For example, in some other implementations, a length of single mode fiber follows the filter to attenuate higher order modes.

20 Fig. 4 is a plot of power as a function of wavelength illustrating the spectral relationships between the active and passive optical components of Fig. 3 embodiment.

Plot 210 illustrates the spectrum of the light emitted by the SLED 142. As illustrated, it is a relatively broadband signal stretching from approximately 1250-
25 1350 nm. The etalon, however, functions as a Fabry-Perot filter to convert the wideband output to a series of spikes spaced at 200 GHz centered around 1300 nm, as noted in plot 212.

Plot 214 illustrates the reflectance of the first WDM filter 140. It is reflective in the 1300 nm range, but transmissive around the 1550 nm range. This allows the combination of the reference signal 111 and the optical signal 14 to produce the combined signal 14/111.

5 Plot 220 shows an exemplary optical signal 14, comprising multiple energy spikes associated with each channel, stretching across the C and L-bands between approximately 1500 nm to over 1600 nm. Spectrally on either side of the channels are two optical service channels 222, 224, which can be used to transmit additional channel information.

10 Plot 216 is the reflectance curve of the third WDM filter 156. It has a sharp transition between the C and L-bands to thereby separate the two bands so that they can be separately detected by the C-band photodiode 158 and the L-band photodiode 160.

Fig. 5 illustrates the integration of the optical channel monitoring system 100
15 on a single, miniature optical bench 134. It also illustrates a second embodiment of the optical channel monitoring system, which does not have separate detectors for the C- and L-bands. Instead, a single detector 160 is used to detect the optical signal. This has the advantage of simplified construction, but negates any opportunity for simultaneous C- and L-band scanning. In one implementation, this
20 embodiment relies on an increased filter spectral range of about 115 nm or greater to scan the entire signal band of interest. In other implementations, the C/L band WDM filter 156 is installed in front of the detector 160 to provide for C or L band scanning only.

Specifically, the fiber 132 is terminated on the bench 134 at a mounting and
25 alignment structure 252. This mounting and alignment structure 252 holds the fiber in proximity to the first collimating lens 136 held on its own mounting and alignment structure 254.

In the reference signal optical train, the SLED 142 generates the broadband beam, which is focused by the second collimating lens 144 held on mounting and alignment structure 256. This collimates the beam to pass through the etalon 146 installed on the bench 134. The reference beam generated by the etalon is reflected
5 by fold mirror 145 to the first WDM filter 140. As a result, the combined beam 14/111 is transmitted to the isolator 138, which is installed directly on the bench 134 in the illustrated implementation.

After the isolator, a focusing lens 148 held on mounting and alignment structure 258 focuses the combined beam onto the tunable filter 150, which is held
10 on the filter mounting and alignment structure 258. The beam from the filter 150 is re-collimated by a third collimating lens 152 held on mounting and alignment structure 260. This beam is then separated into the reference beam and the optical signal by a second WDM filter 154. The reference signal is detected by detector 122. The filtered optical signal is transmitted through the second WDM filter 154 to
15 the signal photodiode 160.

Also shown is the installation of the thermistor 270, which is used by the controller to control the package's thermoelectric cooler

Fig. 6 illustrates the installation of the optical bench 134 into a hermetic package 300. The thermoelectric cooler 310 is installed under the bench 134. The
20 optical fiber 132 passes through an optical fiber feed through 312 to terminate on the optical bench 134. In the figure, the hermetic package 300 has its top removed. Preferably, this is a standard 0.75 x 0.5 inch butterfly hermetic package.

Fig. 7 is a block diagram illustrating the configuration of the tunable filter according to a third embodiment of the present invention. In this embodiment, the
25 tunable filter 150 in Fig. 3, for example, is replaced with the illustrated system.

Specifically, the combined optical signal/reference signal 14/111 from the isolator 138 is sent through a polarization scrambler 410. This yields an unpolarized signal, of which 50% passes through polarization beam splitter 412. The transmitted

signal is indicated by reference numeral 411. The polarization scrambler ensures that the incoming beam has a uniform distribution of polarization states so that the polarization beam splitter always passes exactly 50% of the light. Without the scrambler, the incoming beam could have had its polarization state either parallel or perpendicular to the polarization beam splitter, or an intermediate state, meaning that the transmitted beam would have varied between 0 and 100%.

The optical signal essentially passes through two, series, synchronized Fabry-Perot filter cavities 416. This is accomplished by sending the signal to the right, in Fig. 7, through the tunable filter 150, reflecting the signal with a Faraday mirror 414 and then sending the signal back through the Fabry-Perot cavity 416 a second time. The Faraday mirror 414 has the effect of rotating the polarization of the beam 411 by 90 degrees.

The signal with the rotated polarization is separated by the polarization beam splitter 412 and is output as signal 16. This combined and twice-filtered signal is sent to a detector system 416 including a single detector, a detector system, or L-band, C-band, and reference signal photodetectors 122, 158, 160, depending on the implementation/embodiment.

Alternatively, two discrete, serial, synchronized filters are deployed. Typically an isolator is installed between these two filters.

Fig. 8 illustrates in increased wavelength selectivity obtained by the double pass or two filter cavity arrangement. The transfer function a single pass filter is illustrated by plot 510—whereas in the double-pass configuration, much steeper transfer function is achieved as illustrated by plot 512.

The double-pass or two filter cavity configuration has the advantage of also de-emphasizing any side lobes in the filter's transfer function.

Fig. 9 shows the optical train according to still another embodiment of the present invention. This configuration is termed an optical power monitoring system.

The reference signal is not present. C-band and L-band photodiodes 158, 160, however, are provided. This is useful when the relative spacing or power of the optical channels 12 is important, but not necessarily the absolute wavelengths of those optical channels 12 in the optical signal 14.

- 5 While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

CLAIMS

What is claimed is:

- 5 1. An optical monitoring system, comprising:
 a signal source for an optical signal having spectrally separated channels
 distributed within a spectral band;
 a reference source for generating a reference signal outside of the spectral
 band;
10 a tunable filter that filters the optical signal and the reference signal;
 a reference signal detector for detecting the filtered reference signal; and
 an optical signal detector for detecting the filtered optical signal.
2. An optical monitoring system as claimed in claim 1, further comprising an
 isolator for suppressing back reflections into the signal source.
- 15 3. An optical monitoring system as claimed in claim 1, wherein the signal
 source is a fiber pigtail.
4. An optical monitoring system as claimed in claim 1, wherein the reference
 source comprises:
 a broadband source; and
20 an etalon that generates a reference signal with stable spectral
 characteristics from a broadband signal from the broadband source.
5. An optical monitoring system as claimed in claim 4, wherein the
 broadband source comprises a super-luminescent light emitting diode.
6. An optical monitoring system as claimed in claim 4, wherein the etalon
25 functions as a Fabry-Perot filter to generate a reference signal with spectrally-
 spaced energy peaks from a broadband signal from the broadband source.

7. An optical monitoring system as claimed in claim 1, further comprising a combining filter that inserts the reference signal into a beam path of the optical signal prior to filtering by a tunable filter.
- 5 8. An optical monitoring system as claimed in claim 7, wherein the combining filter is a dichroic filter.
9. An optical monitoring system as claimed in claim 1, further comprising a separation filter that separates the reference signal from the optical signal post filtering by the tunable filter.
- 10 10. An optical monitoring system as claimed in claim 1, wherein the tunable filter simultaneously filters the optical signal and the reference signal.
11. An optical monitoring system as claimed in claim 1, further comprising a processor that calibrates the monitoring system while monitoring the optical signal.
12. A method for optical signal monitoring, comprising:
- 15 receiving an optical signal having spectrally separated channels distributed within a spectral band;
- generating a reference signal;
- actively filtering the optical signal and the reference signal;
- 20 detecting the filtered reference signal while simultaneously detecting the filtered optical signal; and
- analyzing the spectral characteristics of the optical signal by reference to the filtered reference signal.
13. A method as claimed in claim 12, further comprising suppressing back reflections into a signal source.
- 25 14. A method as claimed in claim 12, wherein the step of generating the reference signal comprises:
- generating a broadband signal; and

filtering the broadband signal to generate a reference signal with stable spectral characteristics.

15. A method as claimed in claim 12, further comprising combining the reference signal into a beam path of the optical signal prior to filtering by a tunable filter.

16. A method as claimed in claim 15, further comprising separating the reference signal from the optical signal post filtering by the tunable filter.

17. A method as claimed in claim 10, further comprising filtering the optical signal and the reference signal simultaneously.

18. A method as claimed in claim 10, further comprising:
filtering the optical signal and the reference signal simultaneously; and
calibrating the monitoring system by reference to the reference signal while monitoring the optical signal.

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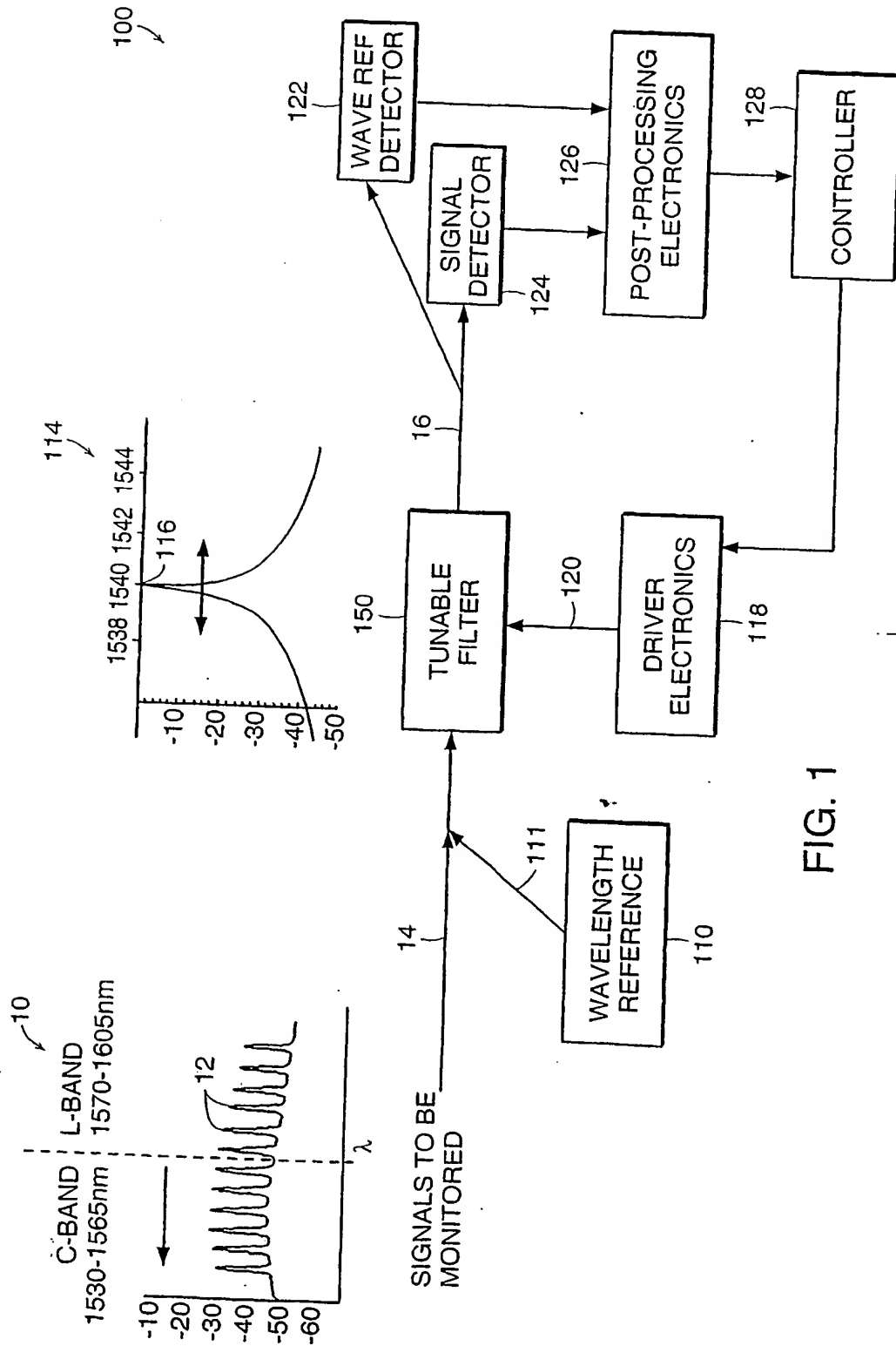


FIG. 1

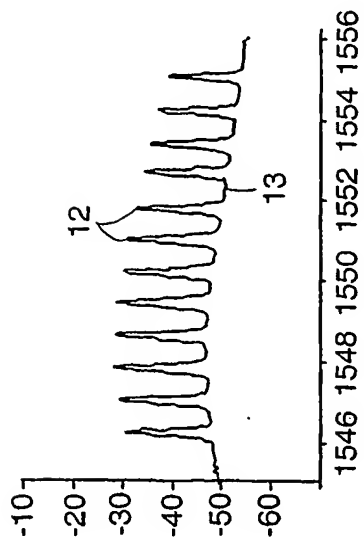


FIG. 2A

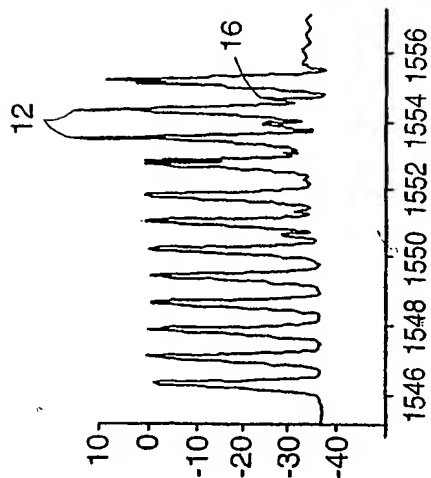


FIG. 2B

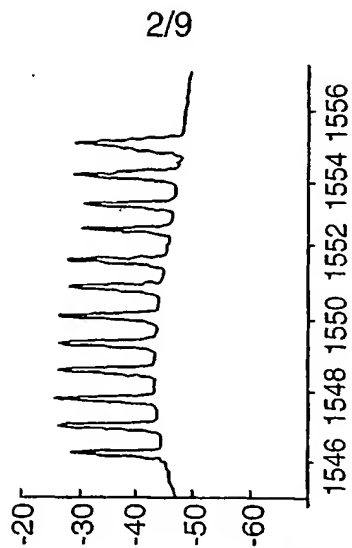


FIG. 2C

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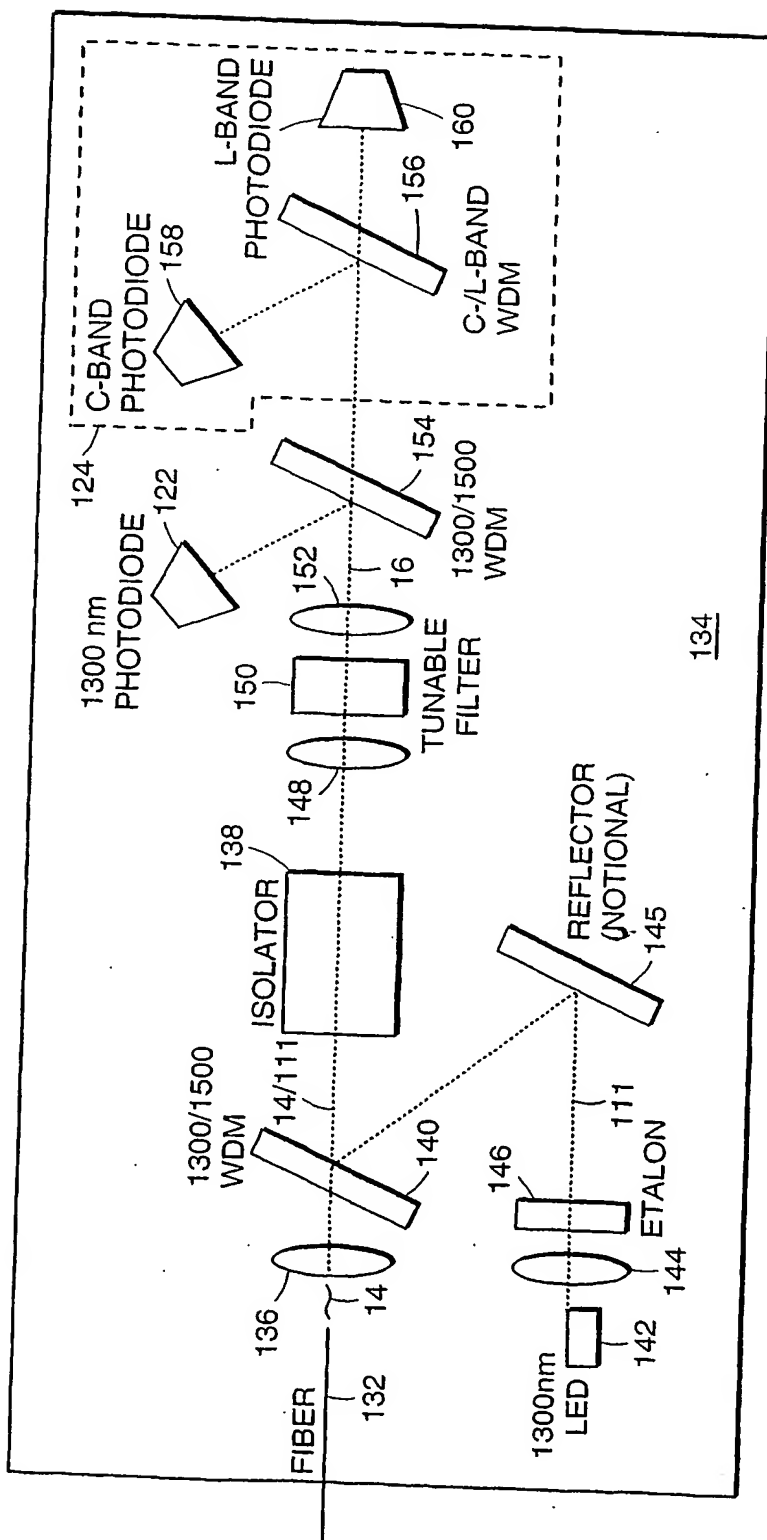


FIG. 3

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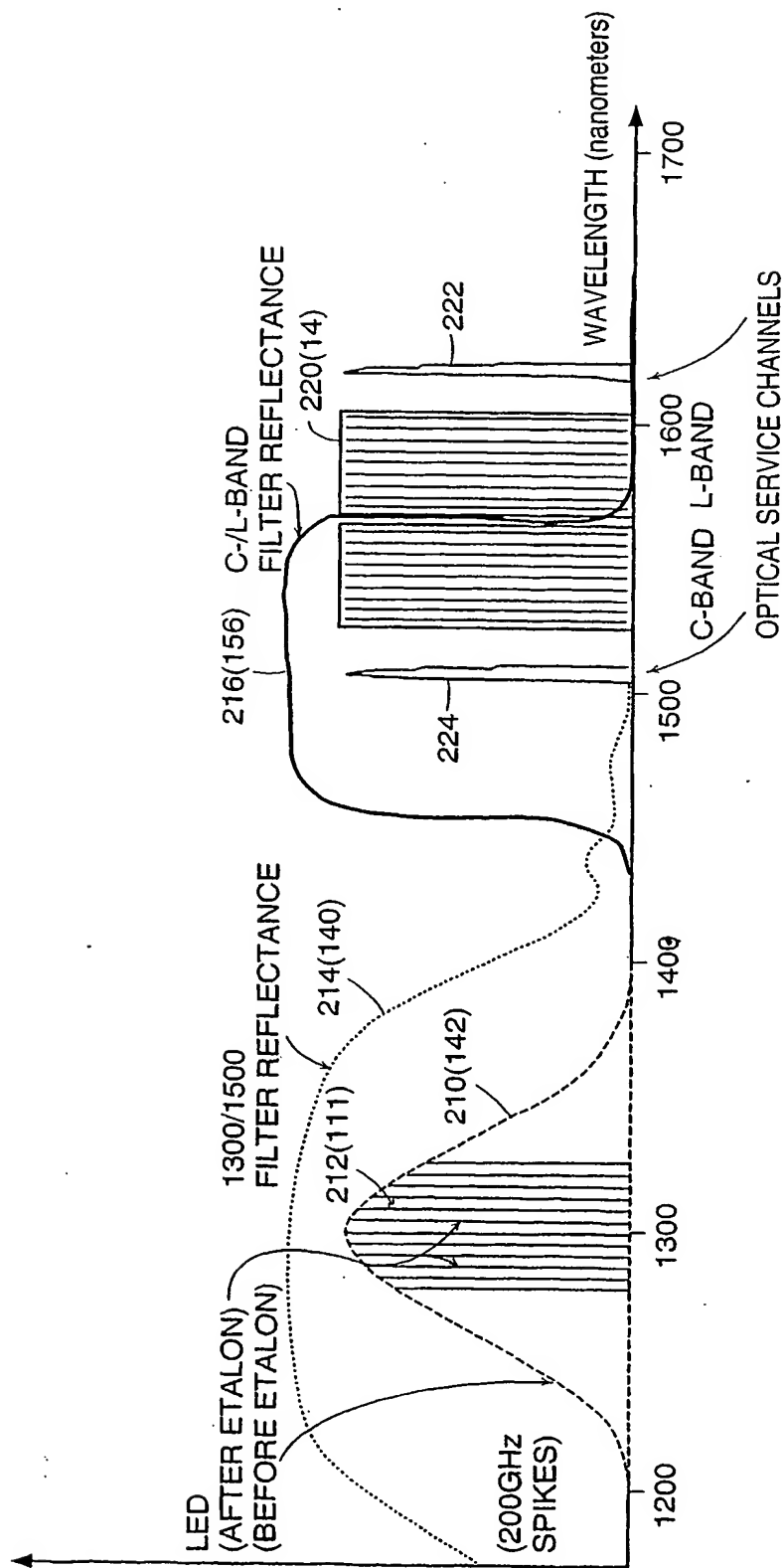


FIG. 4

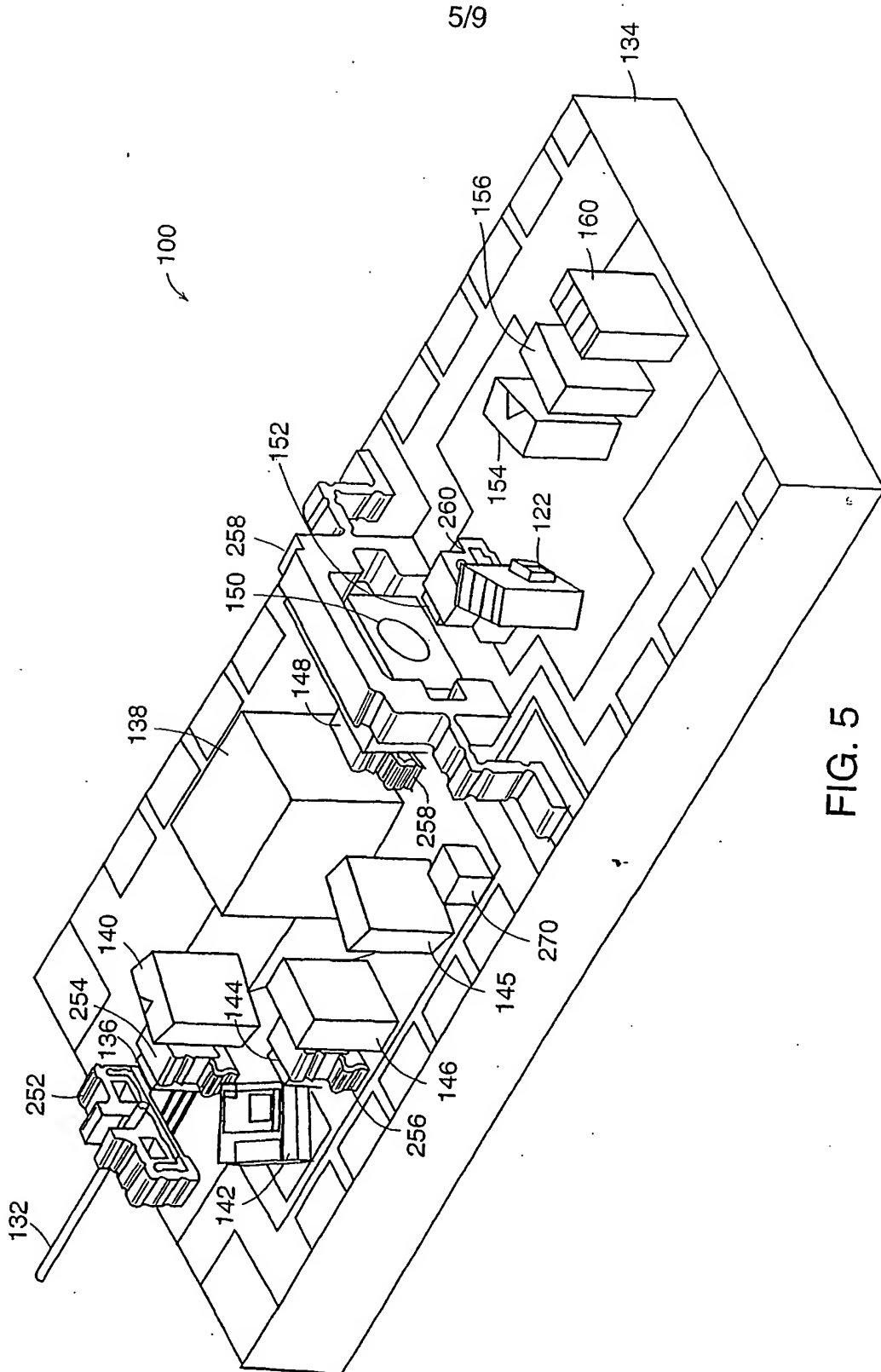


FIG. 5

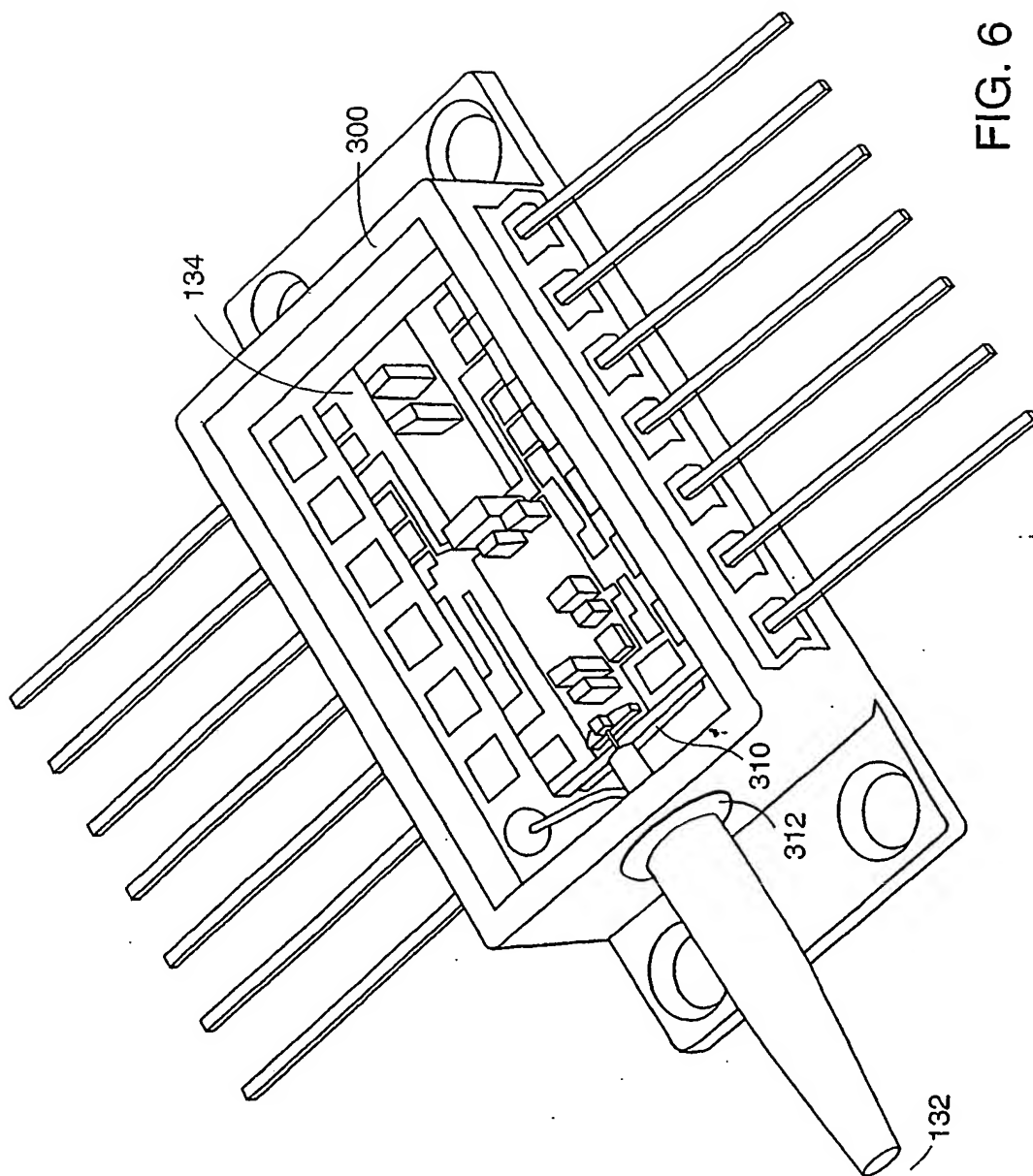


FIG. 6

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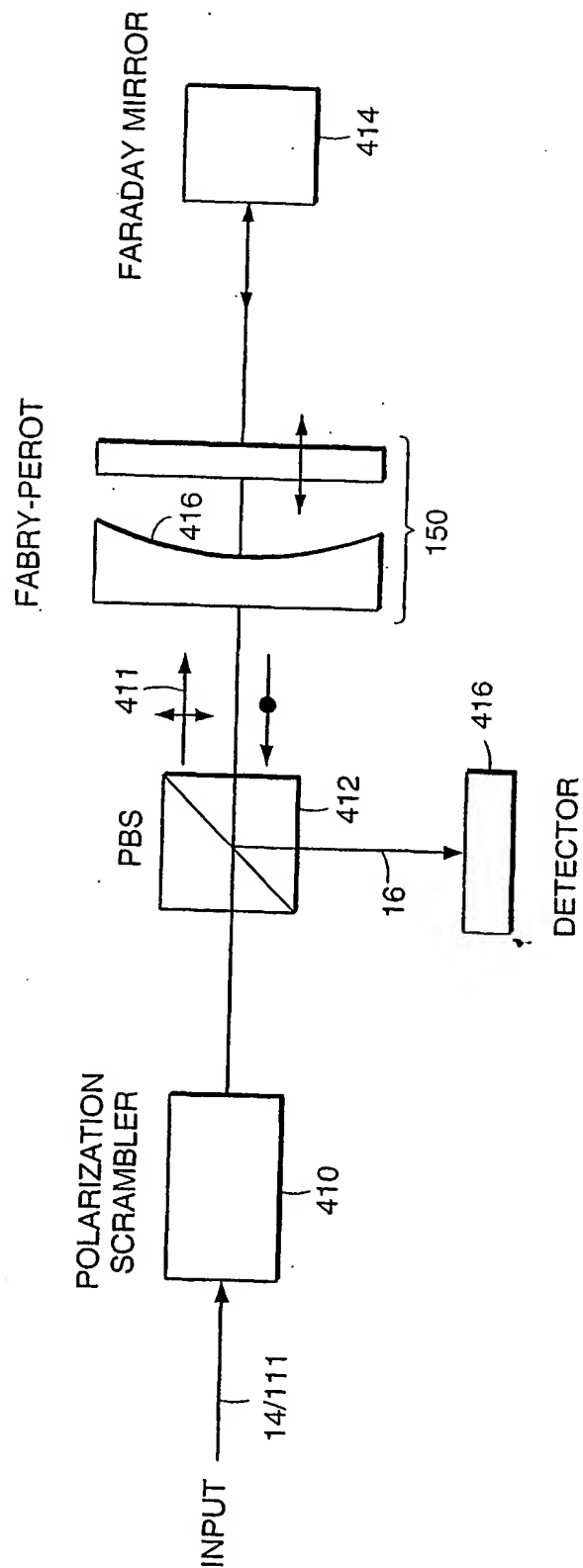


FIG. 7

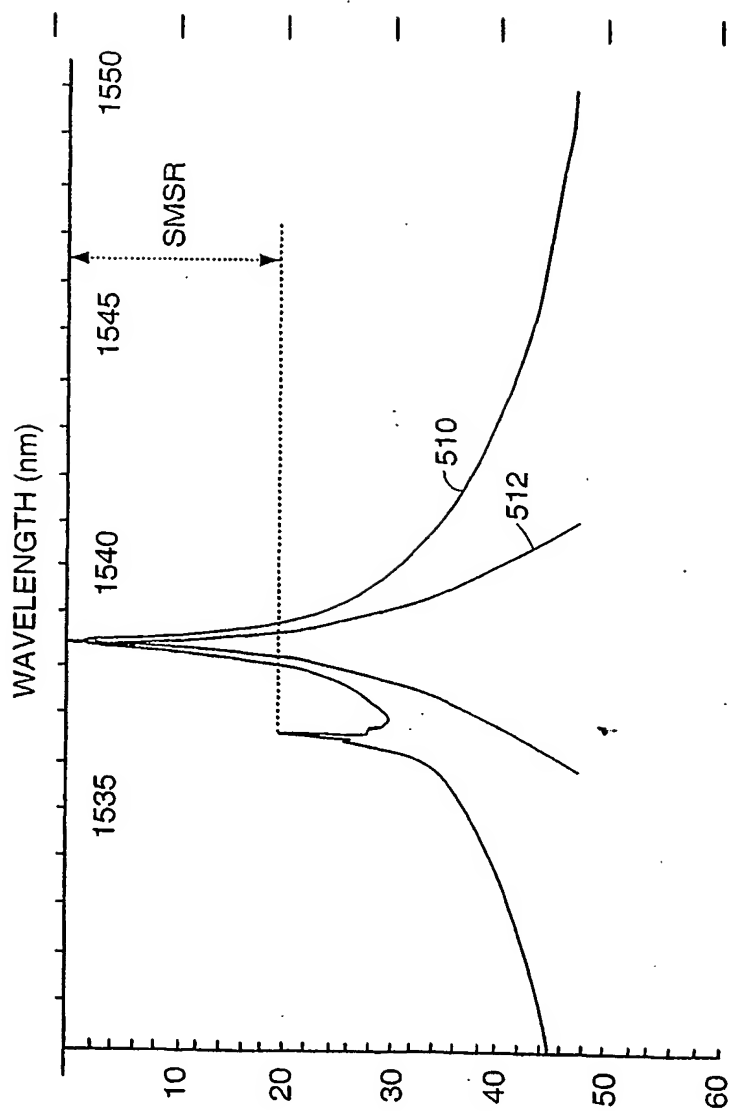


FIG. 8

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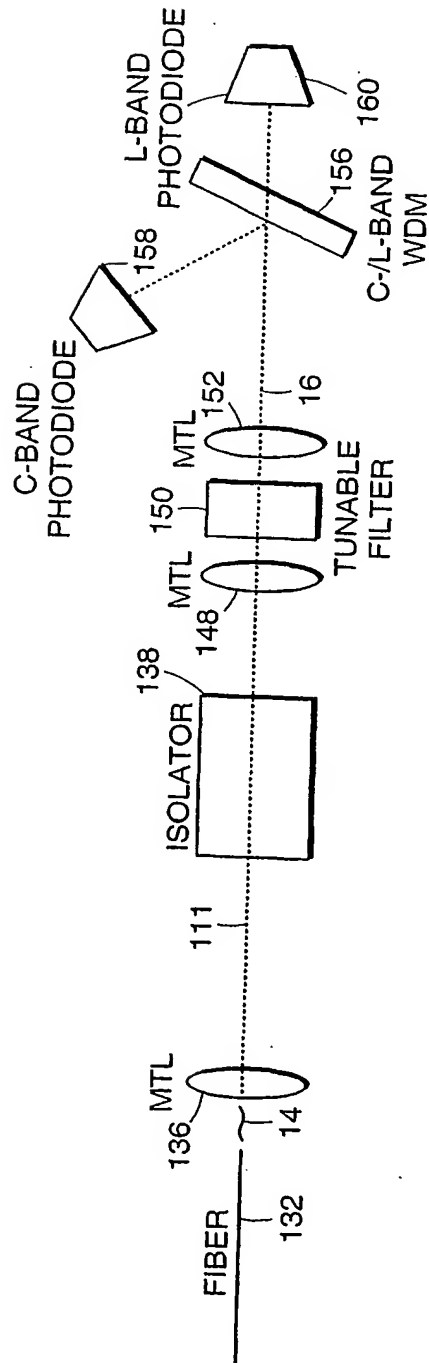


FIG. 9

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H04B10/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, WPI Data, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 773 640 A (AT & T CORP) 14 May 1997 (1997-05-14)	1,3, 10-12, 17,18
Y	abstract column 3, line 22 - line 25 figure 1	4-6,14
X	US 5 798 855 A (ALEXANDER STEPHEN B ET AL) 25 August 1998 (1998-08-25)	1,2,10, 12,13,17
Y	column 10, line 30 - line 48 figure 6	7-9,15, 16
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

10 September 2001

Date of mailing of the international search report

20/09/2001

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INTERNATIONAL SEARCH REPORT

Int. Patent Application No.

PCT/US 01/06856

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 838 437 A (BAO YUFEI · ET AL) 17 November 1998 (1998-11-17) column 6, line 55 - line 59 column 7, line 17 - line 20 figure 2	4-6, 14
Y	SHINJI MATSUOKA: "SUPERVISORY SIGNAL TRANSMISSION METHODS FOR OPTICAL AMPLIFIER REPEATER SYSTEMS" COMMUNICATIONS: CONNECTING THE FUTURE. SAN DIEGO, DEC. 2 - 5, 1990, PROCEEDINGS OF THE GLOBAL TELECOMMUNICATIONS CONFERENCE AND EXHIBITION(GLOBECOM), NEW YORK, IEEE, US, vol. 3, 2 December 1990 (1990-12-02), pages 1846-1850, XP000218888 ISBN: 0-87942-632-2 abstract figure 3	7-9, 15, 16

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/06856

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0773640 A	14-05-1997	US 5646762 A JP 9186673 A	08-07-1997 15-07-1997
US 5798855 A	25-08-1998	US 5532864 A	02-07-1996
US 5838437 A	17-11-1998	AU 4758797 A EP 0932814 A WO 9817969 A US 6115122 A US 6044189 A	15-05-1998 04-08-1999 30-04-1998 05-09-2000 28-03-2000